# ASSESSING THE POST-WINTER THREAT OF GLASSY-WINGED SHARPSHOOTER POPULATIONS

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## ABSTRACT
Glassy-winged sharpshooter (GWSS), *Homalodisca vitripennis*, appears to be limited to discrete regions within the San Joaquin Valley where winter temperatures are mild and the temperature rarely drops below freezing. Prior research indicates that GWSS adults cannot feed at maximum daily temperatures below 50°F (= 10°C), thereby reducing its ability to survive cold winters. We verified the impact of cool temperatures on GWSS adults by exposing them to a regime of seasonal temperatures (within temperature cabinets) that reflect a variety of areas within the state. As expected, mortality rates varied greatly among sites tested, and it appears that mortality is related to both length of exposure as well as intensity of exposure (i.e., amount of cold endured). Using temperature records to calculate numbers of cooling degree days, we constructed ten GIS maps to delineate areas where post-winter GWSS mortality should be substantial, thereby providing a tool to estimate the springtime GWSS threat to different regions. However, estimates of post-winter GWSS mortalities were usually smaller (< 90%) than expected across much of the agricultural production areas of the Central Valley.

## INTRODUCTION
The initial arrival of glassy-winged sharpshooter (GWSS), *Homalodisca vitripennis*, into California's Orange and Ventura counties was predicted to dramatically change Pierce's disease (PD) epidemiology within infested areas (Varela et al. 2001). The insect soon spread into other southern California localities. PD devastated the wine grape industry in the Temecula Valley resulting in significant losses. First detected in Kern County in 1998, GWSS is now present in the San Joaquin Valley. However, the rapid population expansion first observed in southern California appears to be limited to discrete regions within the San Joaquin Valley coincident with citrus production areas where overwintering populations are highest and winter temperatures are relatively mild compared to locations elsewhere in the San Joaquin Valley. Additionally, persistent, localized GWSS populations are present within the urban areas of Fresno, Sacramento, and San Jose Counties where a range of perennial plant host types and slightly elevated daytime high and evening low temperatures might favor the survival and persistence of established populations.

Hoddle (2004) used the climate modeling program "CLIMEX" to estimate the potential worldwide distribution of GWSS. His reported estimates for California (when all localities received supplemental irrigation water) suggested that GWSS could establish reproducing populations along much of the California coast from San Diego north to the Eureka vicinity and within the Central Valley from Bakersfield north to the Redding vicinity. He did propose cold stress as a potential limitation to the establishment of GWSS in states north of California (i.e., Oregon, Washington). However, other observations and studies suggest that low winter temperatures may be the "bottleneck" that limits GWSS survival and distribution in the higher altitudes and northern regions of California (Pollard and Kaloostian 1961, Russell Groves et al., unpublished data from 2003).

CDFA-funded research showed that GWSS adults do not feed near or below 50°F (10.0°C), and that individuals will die if held below 50°F for long periods (e.g., 15 or more days) even in the presence of food and water (Johnson et al. 2006). Also of significant importance is that the overwintering adult cohort is responsible for producing the offspring in the spring, which may start as early as late-February in some southern California areas (Krugner 2007). Given this, if the daily maximum temperature infrequently surpasses the thermal activation threshold (50°F) necessary for GWSS ingestion, then GWSS survivorship may be curtailed by extended periods of cool temperatures in specific microclimatic regions of California. We experimentally showed this phenomenon using programmable, temperature cabinets to simulate fluctuating diurnal temperature regimes based on January temperatures in the locations of Riverside (Riverside County.), Oakville (Napa County), and Buntingville (Lassen County), CA. In our study, the Riverside temperature always exceeded 50°F (= 10°C), and about 20% of the test insects remained alive after 115 days; for Oakville it daily exceeded 50°F for 18 hours and only 10% of GWSS survived after 115 days; and for Buntingville the temperature never reached 50°F, and the entire test group died within 20 days (Youngsoo Son et al., unpublished data). We have applied the concept of cooling degree-days (CDD) to estimate the impact of cool temperatures on GWSS survival. The equation for $CDD_{GWSS}$ may be expressed as:

$$\text{Daily } CDD_{GWSS} = \begin{bmatrix} |T_m - 50|, \text{if } T_m < 50\ ^{\circ}\text{F} \\ 0, otherwise \end{bmatrix}$$

where $T_m$ = daily mean temperature in a given locality, $| T_m - 50 |$ = absolute value of difference between $T_m$ and the feeding threshold of 50°F when the mean daily temperature is lower than 50°F. Daily $CDD_{GWSS}$ equals zero if the daily mean temperature ($T_m$) is higher than 50°F. By summing the $CDD_{GWSS}$ for each day over an extended period, one can estimate the cumulative $CDD_{GWSS}$ over the specified time period for that locality. Using unpublished field data collected by Don Luvisi, Farm Advisor *Emeritus*, in 2001-2002, we plotted the relationship between cumulative $CDD_{GWSS}$ and GWSS survival at various sites in the vicinity of Bakersfield (Kern County). Based on a curvilinear regression, GWSS survival dropped to 0% when about 321 $CDD_{GWSS}$ in °F (or 178 in °C) were accumulated.

Because most of our previous CDFA-funded work on the impact of cool temperatures on GWSS feeding and survival was conducted using constant temperatures, it was necessary to validate our findings under actual fluctuating temperatures in the field. Prior efforts to field-validate the impact of cool winter temperatures on caged GWSS adults in the crop production areas of the San Joaquin Valley (e.g., east and west of Bakersfield, central Fresno and Merced Counties) and farther north (Napa and Sonoma Counties) were prevented due to concerns over potential escapes of GWSS individuals. Fortunately, we were permitted to establish one field test comparing GWSS adults caged in the urban area of Bakersfield versus caged GWSS in Riverside (UCR Citrus Experiment Station). The GWSS individuals died in a shorter amount of time at the cooler Bakersfield site than the Riverside site. However, only one field test of our hypothesis using fluctuating temperatures is inadequate. Therefore, we proposed to test the impacts of fluctuating temperatures on GWSS survival using programmable temperature cabinets as we have done for the study mentioned above. These additional studies would provide insights into the benefits of using cumulative $CDD_{GWSS}$ to estimate GWSS survival. We also planned to analyze historical temperature data for various locations within the agricultural production areas of California to determine if winter conditions (e.g. November to March) would permit significant GWSS survival based on $CDD_{GWSS}$ accumulation. The eventual product that we aim to produce from these efforts will be the production of GIS maps that estimate $CDD_{GWSS}$ accumulation over the winter months to provide estimates of the ability of local GWSS populations to pose a substantial threat to local agriculture in the following growing season (i.e., a risk assessment). As resources for GWSS management dwindle, government agencies will be forced to make decisions on which regions should receive area-wide treatment to suppress GWSS populations. Our studies suggest that the presence of the GWSS threat may vary with the severity of local winter temperatures. An annual estimation of overwintering GWSS survival across agricultural regions will provide insights into where resources for GWSS suppression should be most effectively allocated.

## OBJECTIVES

1. Verify impacts of winter temperatures on GWSS survival from selected California sites;
2. Quantify and compare variation in "cooling degree day" accumulation within and among selected California sites using historical temperature data; and
3. Construct Geographical Information Systems (GIS) maps that estimate GWSS survival during the winter period.

## RESULTS AND DISCUSSION

### Objective 1

Verify impacts of winter temperatures on GWSS survival from selected California sites

Dr. Hannah Nadel conducted experimental studies in temperature-controlled growth chambers at the University of California at Riverside. Laboratory studies were conducted because using live GWSS in field-cage studies was prohibited outside of the GWSS-infested areas of California. Cabinets were programmed to run various fluctuating, diurnal temperature patterns that were representative of historical patterns from selected sites within California's agricultural regions. For nine CIMIS sites (i.e. Riverside, Santa Ynez, Porterville, Merced, Davis, Oakville, McArthur, Gerber, and Arvin), mean daily maximum and minimum temperatures were calculated for the months of November, December, January, February, and March. GWSS adults were caged under a given temperature regime (e.g., McArthur) for a five month period. In chronological order (November, December, January, February, and March), the temperature cabinets were programmed to simulate the average maximum and minimum temperature patterns for the individual months (i.e., 30 days for November, 31 days for December, 31 days for January, etc.). To avoid mortality due to freezing, the minimum temperature was set at 3°C.

Adult GWSS were collected by beat-netting from lemon trees at the UCR Agricultural Operations citrus orchard in Riverside, CA, between late October and early December 2007. They were held on potted sweet orange and prostrate acacia in mesh and vinyl cages in a greenhouse at 25 ± 4°C with natural light (supplemented with sodium vapor lamps L:D 12:12) for 4 – 7 days before use.

Two plant species were selected as winter hosts for the study, 'Washington Navel' orange (*Citrus sinsensis* [L.] Osbeck) grafted on trifoliate orange (*Poncirus trifoliata* [L.] Rafinesque) rootstock, and prostrate acacia (*Acacia redolens* Maslin cv 'prostrata'). Grapevines were not used as originally planned because of difficulty locating nursery stock not treated with insecticides. Prostrate acacia is a leguminous evergreen shrub that is an overwintering host for GWSS (H. Nadel, personal observation). One orange (75 cm tall) (TreeSource Citrus Nursery, Exeter, CA) and one acacia (Parkview Nursery, Riverside, CA) were potted together in a 180 $cm^2$ (7-inch) pot and all plants were acclimated at least 1 month in a greenhouse before the study started. A 3.0 mm layer of white sand was placed over the potting medium to facilitate observation of insects on the soil. A 10-day study revealed that the nursery plants were apparently free of toxic residues.

Exposure of GWSS to simulated November temperatures began on the following dates: Riverside 11/9/07; Arvin 11/14/07; McArthur, Oakville and Merced 11/16/07; Porterville, Gerber and Davis 11/30/07; and Santa Ynez 12/6/07. Five male and five female GWSS were transferred in vials from holding cages to each experimental cage. Seven replicate cages were placed individually in water saucers in each temperature cabinet and the plants and insects allowed to acclimate at 18°C for 24 hours before winter temperature simulations began. Cabinets were lighted from 6:00 AM to 6:00 PM by four 32 W fluorescent tubes and two 15 W incandescent bulbs.

GWSS mortality was recorded weekly. Cages were removed from temperature cabinets only long enough to examine and remove dead insects, and were quickly returned (2-5 min). Insects that appeared to be dead were removed from cages, placed on paper under room temperature (20-21°C), and covered with a clear vial. Those that did not revive within two hours were recorded as dead; revived GWSS were returned to their respective cages. Examination of cages was done during the warmest hours of the simulated day, when the insects were likely to show movement. Dead insects were counted and sexed. The potting medium was kept moist with weekly or biweekly watering, as needed.

Numbers of live and dead individuals were counted weekly until all insects died or the 5-month study period ended. The cumulative $CDD_{GWSS}$ were calculated for each location regime (e.g., Riverside, McArthur) based on temperatures recorded with HOBO recorders within the temperature cabinets (**Table 1**) and percent survival will be compared among regimes using survival analysis. The numbers of cumulative $CDD_{GWSS}$ required to kill all GWSS individuals per cage will be compared across location regimes to determine if the value to kill all test insects remains fairly constant across different diurnal temperature patterns. Mortality in all environments was $\geq$ 97% at the end of the study (**Figure 1**). As expected, all GWSS died in the McArthur environment by early December, after exposure to temperatures below feeding threshold. All insects died in the Davis and Oakville environments before accumulated CDD reached the average predicted value for 100% mortality. Although the Riverside environment accumulated no CDD, ~ 98% of the insects died by the end of the study. A modification of the planned analysis will therefore be necessary, possibly including a senescence function. It was apparent that there was a relationship between the rate of CDD accumulation and how quickly the insects died.

**Objective 2**

Quantify and compare variation in "cooling degree day" accumulation within and among selected California sites using historical temperature data

Daily maximum and minimum temperature data were downloaded for 10 winter periods (November through March 1997 – 2007) from 15 CIMIS stations in several climatic regions of California, including areas expected to be suitable and unsuitable for GWSS winter survival. Two CIMIS stations, Merced and Porterville, were operative less than 10 years prior to 2007, and had only eight and seven years of data, respectively. CDD were calculated for each date and summed for each winter month, then averaged (**Figure 2**). Most of the sites accumulated less than 300 CCDs (based on °C). Five sites accumulated less than 200 cumulative CDDs.

**Objective 3**

Construct Geographical Information Systems (GIS) maps that estimate GWSS survival during the winter period

We produced 10 GIS maps that show estimates of post-winter mortality of GWSS populations (estimated as % mortality) in regions across California following the periods of November through March for each year from 1998-1999 to 2007-2008. These maps were based on temperature data collected during the target months of November through March by CIMIS and the Western Regional Climate Center (WRCC). We estimated the cumulative $CDD_{GWWS}$ based on mean daily temperatures for about 340 temperature monitoring sites. One hundred percent mortality was achieved at 321 cumulative $CDD_{GWWS}$ (based on °F). Spatial statistics techniques using ESRI ArcGIS® Geostatistical Analyst were used to create interpolated surface maps using an Inverse Distance Weighted Analysis with a standard search of 206 points using 15 neighbors (at least 10 were found for each search). Two examples of the maps are provided showing dramatic differences in estimated GWSS mortality in the Central Valley in 1998-1999 (**Figure 3A**) versus 2007-2008 (**Figure 3B**) with much less mortality during the latter period.

Contrary to our initial assumptions, estimated post-winter mortality was not as high as we expected (i.e., 100%) in most of the agricultural areas of the state and was quite variable throughout the ten years examined. Within the Central Valley, estimated GWSS mortality resulting from cool temperatures (that inhibit normal feeding) usually varied from 80 to 95%. Based on these results, we now realize that there is a need to be able to estimate the size of GWSS populations at the end of the winter months as well as the potential for increase in various areas based on climatic conditions. Small post-winter populations in cool areas (Santa Ynez) may not pose a threat to agriculture compared to large post-winter populations in warmer areas (e.g., Merced). Also of importance is the time when GWSS females initiate egg laying in the spring. Egg laying may be as soon as late February in Riverside compared to later dates farther north in cooler areas.

**CONCLUSIONS**

This project has generated significant new information regarding the impact of California winter temperatures on GWSS survival and also provides a practical tool to use in the decision making process for GWSS management. However, estimated post-winter GWSS mortality due to cold inhibition of feeding was smaller (< 90%) than expected across much of the agricultural production areas of the Central Valley in most of the winters for which maps were produced. In much of the Central Valley, mortality estimates ranged from 80 to 90%, which may be insufficient to prevent the initiation of threatening spring populations of the GWSS. However, occasionally estimates were as high as 90 to 99%. Another important factor is geographical location because GWSS populations in southern latitudes are typically able to initiate egg-laying earlier than populations farther north. More northern populations will suffer greater temperature-related mortality before they can initiate egg-laying activities.

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**Table 1.** GWSS adult mortality and total CDD (based on a feeding threshold of 10°C) accrued to reach > 95% mortality.

| CA Site | Accumulated CDD | Mortality (%) | Weeks elapsed |
|---|---|---|---|
| Riverside | 0 | 98.6 | 17 |
| Arvin | 86 | 95.7 | 12 |
| Oakville | 117 | 97.1 | 9 |
| McArthur | 144 | 97.1 | 4 |
| Davis | 145 | 97.1 | 11 |
| Santa Ynez | 154 | 97.1 | 11 |
| Porterville | 221 | 95.7 | 18 |
| Merced | 236 | 97.1 | 21 |
| Gerber | 237 | 96.7 | 16 |

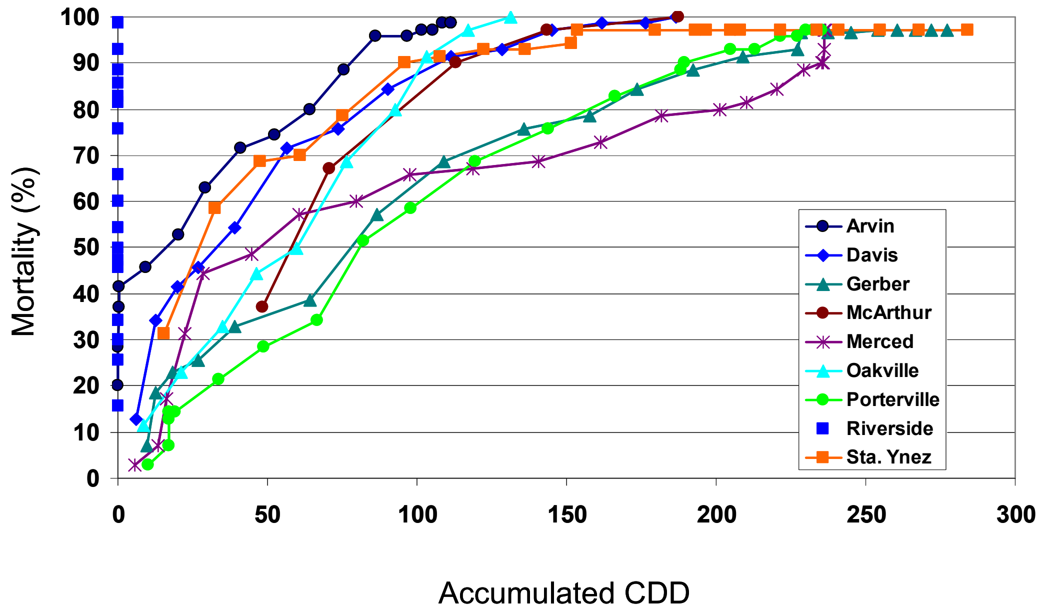


**Figure 1.** Relationship between accumulated CDD (Based on °C) and GWSS mortality under simulated winter conditions for nine California sites. Points represent mean weekly mortality data.

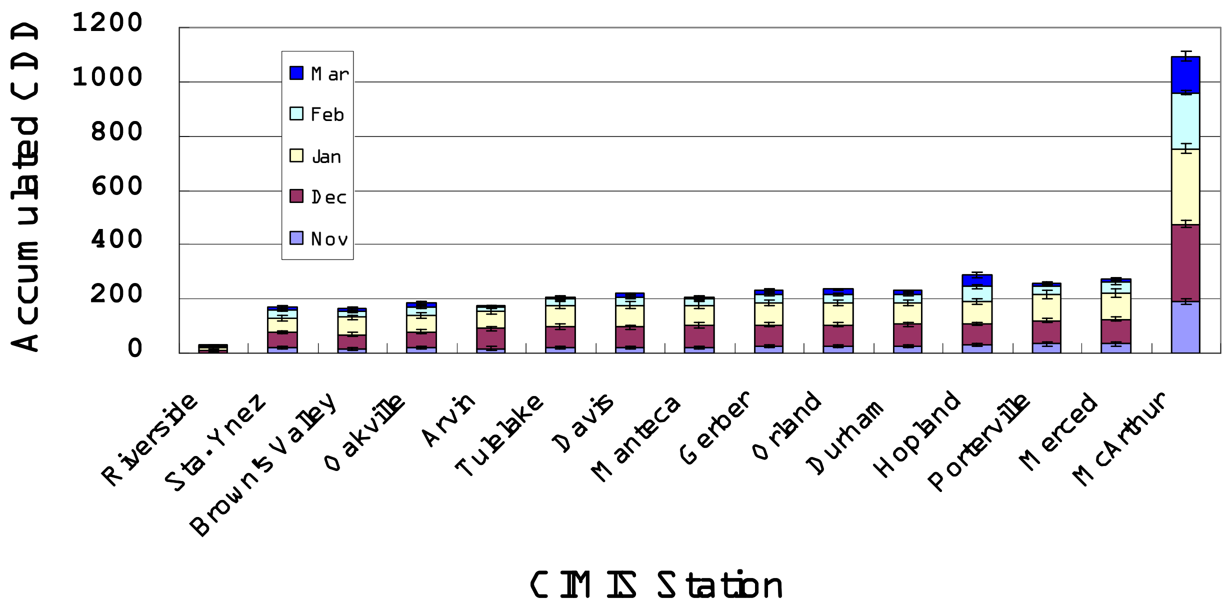


**Figure 2**. Mean (± SEM) accumulated CDD (in ºC) for each winter month at CIMIS sites in California over a recent 10-year period (November 1997 through March 2008). The selected CIMIS stations represent climates in the San Joaquin Valley (Arvin, Porterville, Merced, Manteca), Sacramento Valley (Davis, Brown's Valley, Durham, Orland, Gerber), south coast (Riverside), central coast (Sta. Ynez), north coast (Oakville, Hopland), Cascades Range (McArthur), and Klamath Basin (Tulelake Fire Station).

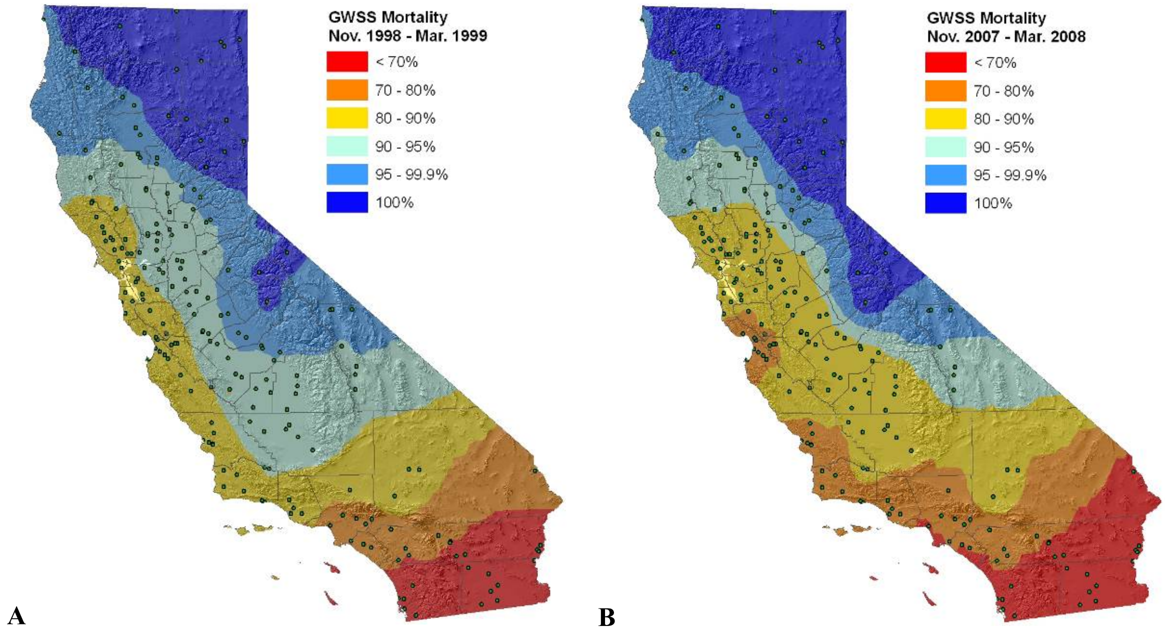


**Figure 3.** Estimated percentage of cold-induced mortality of adult GWSS populations throughout California regions experiencing different levels of cumulative cooling day degrees (CCD) from A) November 1998 thru March 1999 and B) November 2007 thru March 2008. Dark blue represents 100% GWSS mortality (> 321 cumulative CDD based on ºF or > 178 cumulative CDD based on ºC) and red represents 0 to 69% GWSS mortality. Green circles indicate CIMIS weather stations.